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A Teacher–Researcher Partnership for Professional Learning: Co-Designing Project-Based Learning Units to Increase Student Engagement in Science Classes

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ABSTRACT

We present teacher–researcher partnership (TRP) as a way of fostering teachers’ professional learning. Teachers’ participation as research group members is an essential aspect of the partnership. Teachers and researchers share the same goal, which is to improve their understanding of and enhance students’ engagement in science. Project-based learning (PBL) was selected as a means of enhancing student engagement. The activities of the partnership focused on the co-design and enactment of and co-reflection on PBL units. Teachers participated in the design of the data collection process and the interpretation of initial findings. As an indicator of teachers’ professional learning, we examined students’ engagement during different implementations of the PBL units. Student engagement was measured using a situational experience sampling questionnaire delivered via mobile phones. The students’ experiences of scientific practices and engagement in actual learning situations were measured in the first and second years of the teachers’ implementation of the teaching units. An analysis of the students’ responses showed that the students were 20% more engaged in the second year than in the first year. We argue that TRP has the potential to enhance teachers’ professional learning.

KEYWORDS

Professional learning;
partnership; co-design;
project-based learning;
engagement

Introduction

Changing teaching practices and pedagogical approaches is not easy. While Finnish teachers are regarded as highly autonomous professionals who are not subject to the pressures of standardized testing and inspection, they are known for being pedagogically conservative and for generally favoring the direct teaching of large groups of students; furthermore, science inquiry occurs much less in Finnish classes compared with those of other Organization for Economic Co-operation and Development (OECD) countries (Juuti et al., 2010; Krzywacki et al., 2015; Lavonen & Laaksonen, 2009; Loukomies et al., 2018; Norris et al., 1996; Organisation for Economic Co-operation and Development [OECD], 2016). In this paper, we describe teacher–researcher partnership (TRP) as a way of fostering autonomous and expert professional learning among teachers in order to implement change in science education practices in the classroom.

TRP is built on existing understandings of effective professional development and the literature on research–practice partnerships. Coburn and Penuel (2016) define research–

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practice partnerships as “long-term collaborations between practitioners and researchers that are organized for investigating problems of practice and for developing solutions for improving school practice and even school districts” (p. 48). A research–practice partnership bridges the gap between educational research and practice and thus fosters teachers’ professional learning (Coburn & Penuel, 2016).

One of the major challenges for both researchers and practitioners of science education has been how to engage students in science learning (e.g., Mead, 1909; Osborne & Dillon, 2008). Methods of enhancing student engagement have emphasized students’ activities and students’ own responsibility for their learning process (Minner et al., 2010). However, these instructional approaches are challenging to orchestrate, and they place continuous demands on teachers to enhance their professional learning (Capps et al., 2012).

Many simple in-service training programs or short-term professional development programs fail to foster among teachers a deep understanding of the new instructional practices emphasized in contemporary curricula and science education research, such as research on student learning and engagement (Oliveira, 2010). Short-term projects do not provide enough time for the iterative design of teaching units or reflections on teaching units (Hashweh, 2005).

Capps et al. (2012) summarize nine features of effective professional development for teachers in the context of inquiry-based science: 1) sufficient time for learning, 2) support from experts and peers, 3) authentic experience, similar to that which they will later enact in their classroom, 4) coherency with the curriculum, 5) design of lessons, 6) working through learning content as modeled inquiry, 7) time and structure for reflection, 8) transference of the professional development materials to the classroom, and 9) content knowledge. Another recent review of professional learning, the report of the National Academies of Sciences, Engineering and Medicine (2015), introduces a consensus model of professional learning for science teachers with the following features: 1) active participation of teachers in analyzing examples of effective instruction and of student work, 2) a focus on content, 3) alignment with district policies and practices, and 4) sufficient time for repeated practice and reflection on classroom experiences.

Both reviews emphasize the science content of professional development programs and teachers’ active participation in following or experiencing model lessons, planning lessons, and enacting and reflecting on lessons, as well as sufficient duration and support from experts. Both reviews also emphasize teachers as learners—teachers should be guided to reflect on their current teaching practices, obtain experience of and analyze desired practices, try readymade lesson plans, and plan new lessons following instructive examples. However, this seems to position teachers as implementers of instruction who are expected to adopt new methods instead of professionals who are agents of the development of professional practices.

In this paper, we argue that TRP is a promising approach for enhancing teachers’ professional learning. We implemented a partnership with teachers, with whom we shared the common goal of enhancing our understanding of and fostering student engagement (Schneider et al., 2016). The activities during the partnership focused on co-designing, enacting, and co-reflecting on project-based learning (PBL) units (Krajcik & Shin, 2015) and participating in the design of the data collection process and the interpretation of initial findings.

In what follows, we first describe situational engagement as an outcome measurement to evaluate teachers’ professional learning and PBL as a means of engaging students. Second, we describe our approach to TRP. Third, we describe the data collection method to evaluate the extent to which students’ engagement changed during TRP. Finally, we summarize TRP as an approach to teachers’ professional learning.

Situational engagement

Students are engaged in a task when they experience it as highly interesting, find it challenging, and perceive themselves as highly skilled in accomplishing it, that is, the situation is an optimal learning moment (Schneider et al., 2016). At school, interest is an important aspect of an individual's connection to a domain being learned. Interest can be personal, as is the case when a student voluntarily gravitates to the domain, or it can be triggered. Incongruous, surprising, intensive, or personally relevant features can spark interest, while participatory activities, such as PBL, can maintain that triggered situational interest (Hidi & Renninger, 2006; Schneider et al., 2016). Interest and perceptions of being skilled or challenged fluctuate according to the specific learning domain in question and the activities involved. Methodologically, measuring situational engagement requires capturing students' experiences in situ. Therefore, situational engagement measurement differs from retrospective or one-time measurements (e.g., Ainley & Ainley, 2011).

Situational engagement is a useful concept for science teaching because teachers can foster it by choosing pedagogical techniques that constitutes optimal learning moments—namely situations where student experience high interests, skill and challenge. PBL is a pedagogical approach with the potential to trigger and maintain students' interest and balance the challenges of domain-specific learning tasks with the skills required to complete them. The Finnish K-12 curriculum (Finnish National Board of Education, 2015) emphasizes teaching science competencies by familiarizing students with core scientific knowledge and practices in a way that is similar to PBL. Moreover, many of the outcomes of research on science education are in line with the concept of PBL.

Project-based learning

PBL involves students in real-world activities, enabling them to work with the material to be learned. It intimately connects disciplinary content and disciplinary practices. Krajcik and Shin (2015) introduce the following six major features of PBL. First, as is the case for projects, activities and work should generally be aimed at accomplishing the goals of the project. A *driving question* guides the project activities, has relevance, triggers students' interest, and connects students' interests to the learning goals of the curriculum. The driving question can be introduced to students in the context of an anchoring event, such as a teacher demonstration, a hands-on activity, or a video demonstrating that the driving question is feasible, worthwhile, contextual, meaningful, and ethical (Krajcik & Czerniak, 2013). One example of a driving question is "Why do some things stick together and other things do not?" (Mayer et al., 2013). Second, when planning PBL, a teacher should connect core disciplinary ideas with learning expectations (Krajcik et al., 2014). When selecting the learning expectations, the teacher can adjust the challenge of the project and the skills required to meet it. Third, scientific practices should be emphasized to support students' active involvement in learning. Scientific practices are similar to professional practices in the discipline and include asking questions, defining problems, and planning and carrying out investigations (Krajcik & Czerniak, 2013). Inkinen et al. (2020) find that students are more situationally engaged when performing activities involving scientific practices. These practices should be introduced in an order appropriate to the project, and students should be scaffolded. The fourth key feature of PBL is collaboration in finding a solution to the driving question. Student

collaboration and scientific practices can be facilitated using digital tools. Thus, the *use of technology* is the fifth key feature of PBL. Technology enables students to learn scientific content that would otherwise be too challenging and to participate in activities that would otherwise be beyond their skills. Technology can enable students to retrieve, organize, and process information about content related to the driving question, collect new data, analyze data, construct models using educational simulation applications and professional modeling software, and discuss models and other products that mediate learning. Students engaged in PBL work with ideas, data, and models and formulate arguments to communicate their ideas to others. Therefore, the sixth key feature of PBL is the production of artifacts. These artifacts are external publicly shared representations of the learning of the class (Krajcik & Shin, 2015). They can include physical or digital models, animations, simulations, research reports, videos, websites, spreadsheet models, and computer programs. They answer the driving question and are concrete and shareable outcomes of the project. Inkinen et al. (2020) found that in a Finnish sample, students who constructed explanations reported higher levels of engagement. Thus, working with artifacts may foster student engagement.

In general, PBL has the potential to enhance student engagement by focusing on interesting driving questions that connect core curricular ideas with scientific practices. It allows students to collaborate and seek answers to driving questions, increases their perceptions of being skilled through the use of digital applications, and enables them to produce tangible products as project outcomes (Krajcik & Shin, 2015). While co-designing project-based science units in partnership with teachers, we included scientific practices, student collaboration, digital tools, and the production of tangible artifacts to engage students. Moreover, the units emphasize the cumulative learning of practices to ensure that students reach an appropriate level of skills with respect to the challenge of each task (Anderson, 2007; European Union, 2016; Ford, 2015; Tytler, 2014).

Our teacher–researcher partnership

In this section, we describe our TRP, which was aimed at obtaining a better understanding of and fostering student engagement in science by inviting teachers to co-design, enact, and co-reflect on PBL units. The Finnish system was heavily decentralized in the 1990s. Short national-level framework curricula are published approximately once a decade, and teachers have a central role in planning the local curriculum and in organizing the assessment of their own teaching and students' learning. There is no centralized testing in compulsory school and no inspectors. The autonomous role of teachers is an important consideration when organizing activities for professional learning in Finnish schools, in which the curricula, student assessment processes, and quality assurance measures are not controlled by external sources but are internal processes (Krzywacki et al., 2015; Loukomies et al., 2018). Educational policy documents in Finland emphasize that teachers are experts in curriculum development, teaching, and assessment at all school levels (Finnish National Board of Education, 2015). This high level of professional autonomy afforded to teachers needs to be considered when planning professional learning programs.

In the context of the Finnish educational system, formal in-service training and professional development programs are not necessarily optimal approaches to supporting teachers to advance their science teaching. By contrast, TRP for professional learning emphasizes equal participation and acknowledges the importance of combining practical

and academic knowledge to improve educational practice and of conducting research that produces knowledge to inform educational improvements (see Henrick et al., 2017). Therefore, the partnership aims to combine educational research, pedagogical design, and teachers' professional learning.

Our view of TRP is based on Dewey's (1916) notion of shared activity, in which parties share the same goals, ideas, interests, and emotions. In practice, the aim is to achieve the mutual goals of teachers and researchers. In the context of TRP, shared activities mean that teachers and researchers design, implement, and evaluate teaching units together and construct new knowledge about science teaching and learning (see Lavonen et al., 2006). For our TRP, the mutual goal was to obtain an improved understanding of how student engagement in school science can be enhanced by designing teaching units. The activities involved co-designing, implementing, and evaluating teaching units that emphasize scientific practices.

Teachers are considered active agents in the partnership and are responsible for their own learning. They are expected to regulate their learning by setting goals for teaching unit design and by reflecting on and assessing their own learning processes and outcomes (Loukomies et al., 2018; Luft & Hewson, 2014; Pintrich, 2003). In their analysis of survey data, Garet et al. (2001) argue that professional learning activities should not only support teachers' active learning to improve their teaching but also focus on designing teaching units that support students' learning and engagement. Designing, implementing, and reflecting on teaching units enables teachers to contextualize their professional learning. Luft and Hewson (2014) analyze several programs and highlight the importance of the school context for professional learning. This context can either encourage or inhibit changes in teachers' pedagogical practices.

Co-designing is central to TRP (Roschelle & Penuel, 2006) and includes setting goals, designing learning units, and reflecting on experiences and students' outcomes, all of which are conceived as mutual activities. Roschelle and Penuel (2006) characterize co-design as a "highly-facilitated, team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need" (p. 606). Luft and Hewson (2014) argue that teacher collaboration supports professional learning; when working collaboratively, teachers reinforce, build, expand, and challenge their ideas about teaching and student learning (Avalos, 2011; Loughran, 2002; Van den Bergh et al., 2015). Moreover, the co-designing process supports teachers' ownership of the designed materials and their implementation (Ogborn, 2002). Co-designing also supports teachers in developing the capacity to participate in various partnerships (Henrick et al., 2017). In the design phase, a creative and supportive atmosphere is crucial. Teachers and researchers should trust that all ideas and concerns will be acknowledged and that there will be room for the free generation of ideas and positive feedback on all ideas. The constructive evaluation of ideas is also an important part of the active design process. Such a creative, constructive, and supportive environment builds trust, enables teachers to take risks, and allows failures in planning, implementing, and evaluating trial teaching units (Henrick et al., 2017; Loukomies et al., 2018; Rogers, 2003; Sawyer, 2007). Co-designing teaching units was perceived as a way of engaging teachers and enabling them to perform an active role in a professional learning and research project.

Individual and collaborative reflections on beliefs and experiences are essential for professional learning (Bianchini & Colburn, 2000; Mansvelder-Longayroux et al., 2007).

Reflection refers to a process in which beliefs or experiences are recalled, considered, and evaluated, usually in relation to a larger goal (Rodgers, 2002). Collaborating in reflection enables teachers to share their beliefs and experiences and to learn from their experiences of implementing the teaching units they were designing (Hiebert et al., 2002). For our TRP, meetings with teachers were organized, in which experiences of enacting the units could be shared. An atmosphere of trust and psychological safety was emphasized to ensure that teachers shared their successes and difficulties. Reflection in TRP involved teachers not only sharing their experiences but also reflecting on the effects of the designed PBL units in relation to the shared goals of the partnership and on how the various aspects of PBL are connected with student engagement. As described in a later section, the teachers participated in designing a data collection process to measure students' situational engagement. Collaborative reflection sessions were organized, during which the first measurements of students' situational engagement were interpreted by both the teachers and the researchers. The preliminary results were presented a way that connecting them with specific teachers was not possible. The connection between the features of PBL and students' engagement was emphasized. In practice, the statistics specialist in the research group performed a preliminary analysis of one data gathering period. The analysis included the frequencies of scientific practices and measurements of student engagement. The teachers were able to consider the extent to which they emphasized certain features of PBL in their own enactment of the unit and how they did so. After the data presentation, the discussion focused on sharing experiences of how the teachers implemented certain features of PBL and experienced the enactment. They also reflected on the data gathering. This combination of sharing experiences of enacting the units and the preliminary analysis of student situational engagement made it possible to re-design the learning units.

The literature on professional development emphasizes that the duration of a program should be sufficient to allow time for teachers to reflect on and discuss their experiences of various instructional practices in different contexts. Moreover, learning pedagogical content knowledge (related to engagement) is an iterative process. Hashweh (2005) emphasizes that teachers learn pedagogical content knowledge over a prolonged period because of repeated planning, teaching, and reflecting on the most regularly taught topics. As iterations take time to plan, enact, and reflect on and as teachers may teach the same curricular content in consecutive academic years, expecting that changes can be measured after one year is realistic. This does not mean that activities need to be intensive all the time. For our TRP, we held two-day workshops and evening meetings (see [Appendix A](#)). The workshops included an introduction on student engagement and PBL, co-design of the sessions on PBL units, co-design of the data collection, and co-reflection sessions during which the primary student engagement results were interpreted. There was also collaboration between Finnish and US teachers and researchers. There were two visits to the US, in which a group of teachers participated in school visits and PBL workshops. A group of US teachers also visited Finland. However, the two main working methods were the workshops, in which PBL ideas were introduced to the teachers, and collaborative planning sessions of the teaching units. The authors of the present paper were the organizers of the workshops. Altogether, six half-day to two-day workshops were organized in 2015–2017. The first and the second authors visited schools and were the researchers with whom the teachers finalized their teaching units. Authors and other researchers, including doctoral students and post-docs, gave introductory presentations, participated in general discussions, workshops, and reflection sessions. US researchers participated in

workshops annually. Altogether, the Finnish researcher team included three professors, two post-docs, and about six graduate students, whereas the US team included two professors, one professional teacher educator, and several post-docs or graduate students.

Common goals, values, and collaboration are considered essential aspects of research–practice partnerships (Coburn & Penuel, 2016; Nonaka et al., 2006). In this partnership strategy, teachers must be perceived as partners, not as adopters of innovations or objects of professional development activities. Teachers should be regarded as members of the research group and as educational innovators (Loukomies et al., 2018) who are willing to improve their practices by engaging with rigorous educational research. The teachers and researchers in the partnership should appreciate each other’s expertise; teachers are experts in the subject and in praxis, whereas researchers are experts in learning science. Both parties invest time and other resources in the partnership, and parties can learn from their participation.

The aim of TRP in this study was similar to the aims of several other approaches to the development of a professional community or professional practice. For example, Nonaka et al. (2006) argue that changes in professionals’ practices build on professional learning or knowledge creation processes that span individual and group levels in which interacting with peers and seeking help from professional experts are important. Similar ideas are emphasized in relation to communities of practice or learning in the workplace, in which professionals access, adopt, and internalize knowledge that has been developed in the community (Wenger, 1999). Both approaches emphasize social learning, which connects individual learning with the emergence of common practices and the development of knowledge in groups and communities (e.g., Maier & Schmidt, 2015; Paavola & Hakkarainen, 2014). Therefore, networks and partnerships with researchers can support autonomous professional teachers to learn new pedagogies related to science teaching and to generate, reflect on, and share new ideas and pedagogies.

This paper described TRP as a way of fostering teachers’ professional learning. Teachers and researchers have a common goal of understanding and fostering student engagement in science. Student engagement changes between the first and second years of enactment of the co-designed PBL units as an indicator of teachers’ professional learning. Arguing that TRP is a promising approach for enhancing teachers’ professional learning, we pose the following research questions:

- (1) To what extent do the student-reported frequencies of PBL features change?
- (2) To what extent does student-reported engagement associated with the features of PBL change?
- (3) To what extent does student-reported engagement change?

Methods

TRP was connected with an international (Finland–US) research project for which teachers in both countries designed and enacted PBL units. The project included national and international workshops and co-planning sessions with individual teachers or teacher teams from each school and the researchers. It also entailed data collection during the implementation of the co-designed teaching units, as described in [Appendix A](#).

In this paper, we focus on the three years of the partnership. The teachers joined the partnership during its first or second year. Altogether, there were about 20 teachers who

participated in the activities and 11 teachers who enacted a co-designed teaching unit with data gathering. The participating teachers taught physics or chemistry at the middle school or high school level. We matched the units of teachers who taught the same subject and at the same school level, as comparing students' engagement in different subjects or at different school levels was not possible. Therefore, in this analysis, we included those teachers who participated in the partnership and taught the same subject at the same school level in the first and second years. In the end, six teachers' students' responses were included in the analysis. Two of these teachers taught middle school physics, three taught high school chemistry, and one taught high school physics. The teachers were experienced, two of them more than 5 years, two about 10 years, and two more than 20 years of teaching experience. They voluntarily participated in the TRP, and some of them had experience in several projects to develop science teaching. Thus, they may be more familiar than typical Finnish teachers are with active learning approaches, such as inquiry-based science. The teachers enacted two of the co-designed units in their classes. Every teacher had their own teaching units with varying topics, including, for example, Newtonian mechanics, electricity, or structure of matter. For each enactment, data on student situational engagement were gathered.

Data were collected on the PBL features included in the teachers' units and the extent to which the students found the situations engaging in order to co-reflect with the teachers on their enacted units. The data on student engagement were then used to re-design the teaching units through an iterative design process (2015–2017).

To evaluate the influence of PBL on student engagement, we measured students' engagement in learning and their experience of scientific practices. The experience sampling method (ESM) (Csikszentmihalyi & Schneider, 2000; Schneider et al., 2016) was used to evaluate the students' experience of certain scientific practices during the implementation of the co-designed teaching units and the level of student engagement. The ESM provides reliable information about students' feelings, thoughts, and emotions, which vary by situation. Therefore, the ESM improves research quality by diminishing the bias caused by remembering the situation (Bolger et al., 2003).

The ESM questionnaire asked the students to select the scientific practices they engaged with, whether they worked with a computer, and whether they worked in a group. For the question "Which best describes what you were doing in science when signaled?", the students were given the following answers to choose from: (a) asking questions, (b) developing a model, (c) using a model, (d) planning an investigation, (e) conducting an investigation, (f) analyzing data, (g) solving math problems, (h) constructing an explanation, (i) using evidence to make an argument, (j) evaluating information, and (k) others. These options were recoded as dichotomous variables for the analysis (1 = scientific practice was reported, 0 = scientific practice was not reported). Students rated their level of engagement on a four-point Likert scale. The items measuring student engagement were related to the students' situational interest, skills, and challenges. They were as follows: "Did you feel skilled at what you were doing?," "Were you interested in what you were doing?," and "Did you feel challenged by what you were doing?" This triad of skill, interest, and challenge refers to the optimal learning moment (Schneider et al., 2016). A student was interpreted as engaged when the questions relating to all three variables were answered "agree" (3) or "strongly agree" (4), and the binary variable for situational engagement was assigned a value of 1; otherwise, the variable was assigned a value of 0, indicating a low level of engagement (Schneider et al., 2016).

Schneider et al. (2016) describe the development and testing of our ESM instrument. It is important to note that because of the conceptualization of engagement as a high feeling of skill, interest, and challenge, it is not expected that students experience a similar level of skill, interest, and challenge, which are the different dimensions of engagement. Therefore, the reliability coefficient of the simultaneous occurrence of skill, interest, and challenge is not expected to be high. For example, a student experiences a situation as uninteresting when they perceive themselves as highly skilled and less challenged. For another student in the same situation, they could experience it as highly challenging even if they perceive themselves as highly skilled. This indicates the situational fluctuation of various students' experiences and is one strength of the ESM (Schneider et al., 2016).

The data were collected over the period 2015–2017. The ESM questionnaire was delivered via smartphones, which were programmed to notify the students to response the questionnaire three times during each of the six co-designed teaching unit lessons (Inkinen et al., 2020; Schneider et al., 2020). Data gathering was planned together with the teachers. From earlier data collection processes, we found that it takes about two minutes to answer the ESM questionnaire. Teachers were worried about the interruption of the lesson flow by the data gathering. Therefore, we decided to change the random sampling we had earlier (Schneider et al., 2016) to synchronized sampling. All students received the request to respond to the questionnaire at the same time. At the beginning of the lesson, there were typically some classroom management issues or checking of homework involved to ensure that the students were working on their project, and the teachers emphasized that the first data gathering request should not be at the very beginning of the lesson. The sample consisted of six secondary school science classrooms in three schools in the Helsinki area. Altogether, 99 students participated in the first year and 130 students in the second year. This resulted in a total of 1,784 responses to the ESM questionnaire in the first year and 1,734 responses in the second year.

Results

The similarity between two years with different groups by teacher was evaluated using general linear model (GLM) repeated measures (SPSS). In the statistical tests, it was expected that the years would be equal in terms of scientific practices for every teacher's group. An independent sample t-test was applied to evaluate the changes between the years. Equal variances were not assumed because Levene's test for equality variances shows a significance level of 0.05 in almost every case. Furthermore, GLM was first applied by scientific practices with and without controlling for students' responses. There were significant differences between years when student responses were not controlled and when scientific practices were in the model (Table 1).

A one-way ANCOVA was conducted to determine whether a statistically significant difference existed in students' engagement in scientific practices, collaboration, and use of computers across the study years, controlling for individual students (Tables 2 and 3). Out of the 11 practices, there was a significant effect of year on *planning an investigation* (PI), *conducting an investigation* (CI), and *analyzing data* (AD) after controlling for individual students (PI: $F(1.3518) = 7.50, p < .01$; CI: $F(1.3518) = 8.83, p < .01$; AD: $F(1.3518) = 9.46, p < .01$).

Tables 2 and 3 show small changes in the reported frequencies of PBL features between the first and second years. There were statistically significant changes. The students reported that they spent less time planning investigations, conducting investigations, and constructing

Table 1. Year comparisons by general linear model.

	Year 1			Year 2			Mean diff.	p
	Mean	N	Std.	Mean	N	Std.		
Scientific practices without student response control	.139	1784	.003	.127	1737	.003	.012	.002**
Scientific practices with student response control	.136	1784	.003	.130	1737	.004	.006	.313

** $p < 0.01$. The Bonferroni correction was applied to adjust for multiple comparisons.

Table 2. Estimated margin means comparisons of scientific practices after controlling for individual students.

Scientific practices	Year 1		Year 2		Mean diff.	Std. Error	p
	Mean	Std. Error	Mean	Std. Error			
Asking questions	.098	.008	.074	.008	-.023	.013	.077
Developing model	.129	.010	.129	.010	.000	.016	.985
Planning investigation	.088	.007	.053	.007	-.036	.012	.003**
Conducting investigation	.183	.010	.130	.011	-.053	.017	.002**
Constructing explanation	.206	.011	.189	.012	-.017	.019	.371
Using evidence to make an argument	.062	.007	.063	.007	.001	.011	.925
Analyzing data	.214	.012	.269	.012	.055	.020	.006**
Doing something else	.109	.009	.135	.009	.026	.015	.081

** $p < 0.01$. The Bonferroni correction was applied to adjust for multiple comparisons.

Table 3. Estimated margin means comparisons of general features of project-based learning after controlling for individual students.

PBL feature	Year 1		Year 2		Mean diff.	Std. Error	p
	Mean	Std. Error	Mean	Std. Error			
Working on a computer	.044	.005	.052	.005	.007	.009	.394
Working in a group	.130	.008	.129	.008	.000	.014	.983

The Bonferroni correction was applied to adjust for multiple comparisons.

explanations. Their responses also showed that they spent more time analyzing data. The time spent working on a computer or working in a group did not statistically significantly differ between the first and second years. However, the frequency of the students' participation in certain instructional practices tells us very little about what was actually done in the classroom. Therefore, we analyzed the frequencies of situational engagement (optimal learning moments i.e. when student experience high interest when the students perceived themselves as both highly skilled and highly challenged). Tables 4 and 5 show the mean values indicating how often the students reported being engaged with a certain PBL feature.

A comparison of the first and second years shows that several features of PBL were reported to be more engaging in the second year than in the first year. Moreover, the level of engagement in "doing something else" did not change and was, especially in the second year, lower than the level of engagement in scientific practices, collaboration, and the use of a computer. Although the students reported that they spent less time planning and conducting investigations and constructing explanations, they reported that they were more engaged in these activities when they did participate in them. They also reported being more engaged in analyzing data and working in groups. Table 6 shows that in the first year, 22% of the situations were reported to be engaging compared with 27% in the second year. This constitutes a statistically significant increase in situational engagement of approximately 20% between the first and second years.

Table 4. Changes in reported situational engagement for scientific practices.

Science practice	Year 1		Year 2		Mean Diff	Std. Error	p
	Mean	Std. Error	Mean	Std. Error			
Asking questions	.24	.048	.37	.043	.14	.074	.067
Developing model	.27	.037	.36	.033	.10	.054	.075
Planning investigation	.12	.046	.36	.048	.24	.078	.003**
Conducting investigation	.11	.026	.30	.030	.19	.045	<.000***
Constructing explanation	.24	.029	.35	.030	.11	.049	.031*
Using evidence to form an argument	.19	.045	.30	.050	.11	.075	.147
Analyzing data	.22	.024	.30	.026	.09	.040	.035*
Doing something else	.15	.013	.28	.017	.01	.024	.608

*** $p < .000$. * $p < 0.05$ **Table 5.** Changes in reported situational engagement for features of project-based learning.

PBL feature	Year 1		Year 2		Mean Diff	Std. Error	p
	Mean	Std. Error	Mean	Std. Error			
Working on a computer	.09	.063	.35	.051	.25	.099	.011*
Working in a group	.16	.028	.26	.024	.10	.041	.017*

*** $p < .000$. * $p < 0.05$ **Table 6.** Changes in reported situational engagement after controlling for individual students in all situations.

Year 1			Year 2			Mean diff.	Std. Error	p
Mean (%)	N	Std. Error	Mean (%)	N	Std. Error			
.22	1784	.012	0.27	1737	.269	.05*	-.020	.020

*** $p < .000$. * $p < 0.05$

Discussion

In this paper, we described our TRP and argued that inviting teachers as members of the research group is a way of fostering teachers' professional learning. We (researchers and teachers) had a shared interest in better understanding and fostering student engagement. Our approach was to co-design PBL units together with teachers. Teachers enacted the units in the first year of their participation, and after co-reflection, the teaching units were revisited; teachers enacted the teaching units again in the second year. Therefore, it was natural to use changes in student engagement as an indicator of teachers' learning.

The first research question focused on students' experience of the frequencies of the PBL features in the first and second years. According to the analysis, there were small changes in the frequencies of the PBL features. The students reported using less time with laboratory activities, such as planning and conducting investigations, whereas they reported using more time in working with knowledge, such as analyzing data.

The second research question focused on the reported engagement associated with the PBL features. There were only small changes in the frequencies of the PBL features and more changes in how engaging such features were. The students reported planning and conducting investigations, constructing explanations, analyzing data, working with a computer, and collaborating with others to be more engaging in the second year than in the first year.

The third research question focused on the general change in student engagement. The analysis showed that there was a 20% increase in situations in which the students

reported being engaged (i.e., experienced simultaneous high interest, high skill, and high challenge).

In summary, based on the analysis, we argue that teachers learned to make their science lessons more engaging. However, the changes in PBL features were rather small. This implies that the frequencies of specific PBL features are not the key to enhancing student engagement. How teachers introduce such features may be more important.

There are six main features of the PBL (Krajcik & Shin, 2015), but only three of them were possible to grasp with the ESM questionnaire. This can be considered a limitation of this research. The three other features may have an important role in fostering student engagement. Therefore, ESM needs to be complemented by video observation methods to analyze how driving questions are introduced and revisited during the teaching unit, what the nature of collaboration is, and how students use computers.

When planning the activities for the partnership, we emphasized mutual goals, teachers as autonomous professionals, and collaboration between teachers and between teachers and researchers during the workshops and during the process of designing the units. These aspects are aligned with the findings of research on teacher education (Linn, 2009; National Academies of Sciences, Engineering and Medicine, 2015; Sowder, 2007; Yoon & Kim, 2010). We emphasized engaging teachers in ongoing learning science research as an approach to improving educational practices (see Henrick et al., 2017). Teachers who participated in the partnership were not regarded as implementers of a certain technique or method but rather as participants in shared activities that would lead to the development of teaching units to achieve shared goals. The partnership required mutual trust and an understanding of the participants' previous knowledge. Furthermore, the partnership activities were not aimed at designing teaching units *for* teachers but rather *with* teachers. Teachers were willing to spend extra time co-planning the units, which implies that they valued the opportunity to co-design the units with the researchers. We interpret this as an indication of the teachers' commitment to the partnership. They were open about difficulties and unsuccessful lessons or units, and we felt that they were willing to find the reasons for these difficulties and to develop more successful lessons. This can be perceived as evidence of a knowledge creation process in which teachers and researchers collaborate and seek help from professional experts (Nonaka et al., 2006). Tension exists between the teachers' responsibility of creating actual lesson plans and their implementation of the co-designed teaching units. As Loukomies et al. (2018) emphasize, negotiating and sharing ideas with individual teachers is important in this kind of partnership in order to enable them to incorporate the co-designed elements into concrete lesson plans.

As Finnish teachers are considered to be pedagogically conservative and to favor direct teaching over inquiry-based science approaches (Juuti et al., 2010; Lavonen & Laaksonen, 2009 Organisation for Economic Co-operation and Development, 2016) and they have a high level of professional autonomy (Krzywacki et al., 2015; Loukomies et al., 2018), we argue that connecting practice to research data through reflection and participation in research projects is an important element of teachers' professional learning. When data collection is co-designed, teaching is not evaluated by external authority; rather, teachers have agency in reflecting on and analyzing student engagement, as in our case, or in understanding better learning processes, in general.

Conclusions

In general, a research–practice partnership is perceived as a way of bridging the gap between educational research and practice and of supporting professional learning (Coburn & Penuel, 2016). We propose the following three main aspects of a research–practice partnership:

- (1) Teachers as members of the research group with shared goals
- (2) Co-design of teaching units
- (3) A focus on ongoing educational research

The first aspect means inviting teachers to participate as members of the research group with shared goals. They are not just engaged in activities to reach the goals of others but rather use their time and mental resources to achieve common goals. This fosters mutual trust and provides a space for conducting trials. It ensures that ideas are taken seriously and that everyone builds on the ideas of others (see Lavonen et al., 2006).

The second aspect of partnership is the co-design of teaching units. This involves conducting sessions during which teachers and researchers plan teaching units together. This makes the activities contextual. After the teachers have enacted the lessons, there is a joint reflection session, in line with the practices described in reviews of the literature on professional learning (Capps et al., 2012; National Academies of Sciences, Engineering and Medicine, 2015).

The third aspect is a focus on educational research. Teachers are involved in co-designing the data collection process and co-interpreting the preliminary results of the first data analysis. They are not researchers, but they are involved in the research project. Co-design entails collaboration not only between teachers but also between teachers and researchers (Maier & Schmidt, 2015; Nonaka et al., 2006; Paavola & Hakkarainen, 2014). According to Biesta and Burbules (2003), knowledge and action are intimately connected, and knowledge emerges from action. Reflection is necessary to generate knowledge from action. Rodgers (2002) emphasizes that reflection involves rigorous and systematic thinking. To foster this kind of thinking, the researchers and the teachers who participated in the project discussed the aspects of the research, such as its aims, methods, and expected outcomes. Various research data were gathered during the project and used to support reflection. The preliminary results were introduced to the teachers and interpreted in collaboration with them. Together, they reflected on the implementation of the co-designed teaching units and interpreted the research results. This approach is intended to enable teachers to focus on the consequences of their actions.

TRP positions teachers as knowledgeable and expert professionals who are agents of their own professional learning. A statement from one of the teachers deserves emphasis: “I always think about research outcomes, such as how to engage students, when I am planning the lessons.” Reflecting on research outcomes while planning lessons implies a professional attitude to teaching. Participation in the partnership project, including the formal workshops, the co-designing sessions, the implementation of the teaching units, and the reflection on the research data, may not require much time. In the case described here, substitute teachers were needed to cover teachers’ lessons a few times per semester over the two-year period. Ideally, this structure of activities should facilitate recursive social, psychological, and intellectual processes at the school level and among individual teachers (Yeager &

Walton, 2011). If teachers engage in the process of research-oriented thinking, they may be willing to participate in a future community of practice (Wenger, 1999), where research-informed practice is valued. Facilitating this kind of thinking among teachers in the future is important. The idea is not to adopt certain teaching methods or approaches but to learn how to implement research knowledge in everyday lesson planning, lesson delivery, and reflection. We believe that TRP is a promising approach to achieve this kind of competence.

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References

- Ainley, M., & Ainley, J. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about science. *Contemporary Educational Psychology*, 36(1), 4–12. <https://doi.org/10.1016/j.cedpsych.2010.08.001>
- Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 807–830). Lawrence Erlbaum Associates.
- Avalos, B. (2011). Teacher professional development in teaching and teacher education over ten years. *Teaching and Teacher Education*, 27(1), 10–20. <https://doi.org/10.1016/j.tate.2010.08.007>
- Bianchini, J. A., & Colburn, A. (2000). Teaching the nature of science through inquiry to prospective elementary teachers: A tale of two researchers. *Journal of Research in Science Teaching*, 37(2), 177–209. [https://doi.org/10.1002/\(SICI\)1098-2736\(200002\)37:2<177::AID-TEA6>3.0.CO;2-Y](https://doi.org/10.1002/(SICI)1098-2736(200002)37:2<177::AID-TEA6>3.0.CO;2-Y)
- Biesta, G. J. J., & Burbules, N. C. (2003). *Pragmatism and educational research*. Rowman & Littlefield.
- Bolger, N., Davis, A., & Rafaeli, E. (2003). Diary methods: Capturing life as it is lived. *Annual Review of Psychology*, 54(1), 579–616. <https://doi.org/10.1146/annurev.psych.54.101601.145030>
- Capps, D., Crawford, B., & Constan, M. (2012). A review of empirical literature on inquiry professional development: Alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*, 23(3), 291–318. <https://doi.org/10.1007/s10972-012-9275-2>

- Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships: Outcomes, dynamics, and open questions. *Educational Researcher*, 45(1), 48–54. <https://doi.org/10.3102/0013189X16631750>
- Csikszentmihalyi, M., & Schneider, B. (2000). *Becoming adult*. Basic Books.
- Dewey, J. (1916). *Democracy and education*. Macmillan.
- European Union. (2016). *Horizon 2020. Work Programme 2016–2017: Science with and for Society* (European Commission Decision C [2016] 1349 of 9 March 2016). European Commission.
- Finnish National Board of Education. (2015). *The national core curriculum for upper secondary education*. http://www.oph.fi/download/172121_lukion_opetusuunnitelman_perusteet_2015.docx
- Ford, M. J. (2015). Educational implications of choosing “practice” to describe science in the next generation science standards. *Science Education*, 99(6), 1041–1048. <https://doi.org/10.1002/sce.21188>
- Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Education Research Journal*, 38(4), 915–945. <https://doi.org/10.3102/00028312038004915>
- Hashweh, M. (2005). Teacher pedagogical constructions: A reconfiguration of pedagogical content knowledge. *Teachers and Teaching: Theory and Practice*, 11(3), 273–292. <https://doi.org/10.1080/1345600500105502>
- Henrick, E. C., Cobb, P., Penuel, W. R., Jackson, K., & Clark, T. (2017). *Assessing research-practice partnerships: Five dimensions of effectiveness*. William T. Grant Foundation.
- Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, 41(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4
- Hiebert, J., Gallimore, R., & Stigler, J. (2002). A knowledge base for the teaching profession: What would it look like and how can we get one? *Educational Researcher*, 31(5), 3–15. <https://doi.org/10.3102/0013189X031005003>
- Inkinen, J., Klager, C., Juuti, K., Schneider, B., Salmela-Aro, K., Krajcik, J., & Lavonen, J. (2020). High school students’ situational engagement associated with scientific practices in designed science learning situations. *Science Education*, 104(4), 667–692. <https://doi.org/10.1002/sce.21570>
- Juuti, K., Lavonen, J., Uitto, A., Byman, R., & Meisalo, B. (2010). Science teaching methods preferred by grade 9 students in Finland. *International Journal of Science and Mathematics Education*, 8(4), 611–632.
- Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, 25(2), 157–175.
- Krajcik, J. S., & Czerniak, C. M. (2013). *Teaching science in elementary and middle school: A project-based approach*. Taylor and Francis.
- Krajcik, J., & Shin, N. (2015). Project-based learning. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 275–297). Cambridge University Press.
- Krzywacki, H., Lavonen, J., & Juuti, K. (2015). There are no effective teachers in Finland – only effective systems and professional teachers. In O.-S. Tan & W.-C. Liu (Eds.), *Teacher effectiveness: Capacity building in a complex learning era* (pp. 79–103). Cengage Learning.
- Lavonen, J., Juuti, K., Aksela, M., & Meisalo, V. (2006). A professional development project for improving the use of information and communication technologies in science teaching. *Technology, Pedagogy and Education*, 15(2), 159–174.
- Lavonen, J. & Laaksonen, S. (2009). Context of teaching and learning school science in Finland: Reflections on PISA 2006 results. *Journal of Research in Science Teaching*, 46(8), 922–944.
- Linn, M. C. (2009). Foreword. In J. K. Falk & B. Drayton (Eds.), *Creating and sustaining online professional learning communities*. Teachers College, Columbia University.
- Loughran, J. (2002). Effective reflective practice: In search of meaning in learning about teaching. *Journal of Teacher Education*, 53(1), 33–43. <https://doi.org/10.1177/0022487102053001004>
- Loukomies, A., Juuti, K., & Lavonen, J. (2018). Teachers as educational innovators in inquiry-based science teaching and learning. In O. E. Tsivitanidou, P. Gray, E. Rybska, L. Louca, & C. P. Constantinou (Eds.), *Professional development for inquiry-based science teaching and learning* (pp. 185–201). Springer.

- Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In S. K. Abell & N. Lederman (Eds.), *Handbook of research on science education* (2nd ed., pp. 889–909). Routledge.
- Maier, R., & Schmidt, A. (2015). Explaining organizational knowledge creation with a knowledge maturing model. *Knowledge Management Research & Practice*, 13(4), 361–381. <https://doi.org/10.1057/kmrp.2013.56>
- Mansvelder-Longayroux, D. D., Beijaard, D., & Verloop, N. (2007). The portfolio as a tool for stimulating reflection by student teachers. *Teaching and Teacher Education*, 23(1), 47–62. <https://doi.org/10.1016/j.tate.2006.04.033>
- Mayer, K., Damelin, D., & Krajcik, J. S. (2013). Linked in: Using modeling as a link to other scientific practices, disciplinary core ideas, and crosscutting concepts. *The Science Teacher*, 80(6), 57–62.
- Mead, G. H. (1909). Teaching of science in college. *Science*, 24(613), 390–397. <https://doi.org/10.1126/science.24.613.390>
- Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474–496. <https://doi.org/10.1002/tea.20347>
- National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. The National Academies Press. <https://doi.org/10.17226/21836>.
- Nonaka, I., von Krogh, G., & Voelpel, S. (2006). Organizational knowledge creation theory: Evolutionary paths and future advances. *Organization Studies*, 27(8), 1179–1208. <https://doi.org/10.1177/0170840606066312>
- Norris, N., Asplund, R., MacDonald, B., Schostak, J., & Zamorski, B. (1996). *An independent evaluation of comprehensive curriculum reform in Finland*. National Board of Education.
- Ogborn, J. (2002). Ownership and transformation: Teachers using curriculum innovations. *Physics Education*, 37(2), 142–146. <https://doi.org/10.1088/0031-9120/37/2/307>
- Oliveira, A. W. (2010). Improving teacher questioning in science inquiry discussions through professional development. *Journal of Research in Science Teaching*, 47(4), 422–453. <https://doi.org/10.1002/tea.20345>
- Organisation for Economic Co-operation and Development. (2016). *PISA 2015 results (volume I): Excellence and equity in education*. OECD Publishing. <https://doi.org/10.1787/9789264266490-en>
- Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. The Nuffield Foundation.
- Paavola, S., & Hakkarainen, K. (2014). Trialogical approach for knowledge creation. In S. C. Tan, H. J. So, & J. Yeo (Eds.), *Knowledge creation in education* (pp. 53–73). Springer Singapore.
- Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching context. *Journal of Educational Psychology*, 95(4), 667–686. <https://doi.org/10.1037/0022-0663.95.4.667>
- Rodgers, C. (2002). Defining reflection: Another look at John Dewey and reflective thinking. *Teachers College Record*, 104(4), 842–856. <https://doi.org/10.1111/1467-9620.00181>
- Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- Roschelle, J., & Penuel, W. R. (2006). *Co-design of innovations with teachers: Definition and dynamics. ICLS '06: Proceedings of the 7th international conference on learning sciences* (pp. 606–612). <https://dl.acm.org/doi/10.5555/1150034.1150122>
- Sawyer, K. (2007). *Group genius*. Basic Books.
- Schneider, B., Krajcik, J., Lavonen, J., Salmela-Aro, K., Broda, M., Spicer, J., Bruner, J., Moeller, J., Linnansaari, J., Juuti, K., & Viljaranta, J. (2016). Investigating optimal learning moments in U.S. and Finnish science classes. *Journal of Research in Science Teaching*, 53, 400–421.
- Schneider, B., Krajcik, J., Lavonen, J., Geller, M. J., & Salmela-Aro, K. (2020). *Learning science – The value of crafting engagement in science environments*. Yale University Press.
- Sowder, J. T. (2007). The mathematical education and development of teachers. In F. K. Lester Jr. (Ed.), *Second handbook of research on mathematics teaching and learning* (2nd ed., pp. 157–224). National Council of Teachers of Mathematics.

- Tytler, R. (2014). Attitudes, identity, and aspirations toward science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 82–103). Routledge.
- van den Bergh, L., Ros, A., & Beijaard, D. (2015). Teacher learning in the context of a continuing professional development programme: A case study. *Teaching and Teacher Education*, 47(1), 142–150. <https://doi.org/10.1016/j.tate.2015.01.002>
- Wenger, E. (1999). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.
- Yeager, S. D., & Walton, G. M. (2011). Social-psychological interventions in education: They're not magic. *Review of Educational Research*, 81(2), 267–301. <https://doi.org/10.3102/0034654311405999>
- Yoon, H. G., & Kim, M. (2010). Collaborative reflection through dilemma cases of science practical work during practicum. *International Journal of Science Education*, 32(3), 283–301. <https://doi.org/10.1080/09500690802516538>

Appendix A. Workshops and support during the partnership

Year	Workshop	Topics
2014	Three-day workshop, May 5–7 (US)	<ul style="list-style-type: none"> - Three-dimensional learning (combining scientific practices, core scientific concepts, and core disciplinary ideas) - Modeling based on empirical data - Use of simulations to support revised model construction
2015	Two-day workshop, January 19–20 (Finland)	<ul style="list-style-type: none"> - Planning a science investigation - Use of evidence when forming a scientific argument - Modeling based on empirical data and improvement of models based on a new investigation
2015	Two-day workshop, January 26–27 (Finland)	<ul style="list-style-type: none"> - Teaching unit planning in small collaborative groups - Introduction of teaching units and planning of revised models based on feedback
2015	February (in participating Finnish schools) <i>Implementation and data collection in Finnish schools</i>	<ul style="list-style-type: none"> - Teaching unit planning by a group of teachers on the school site - Researcher visit to the school site
2015	One-day workshop, May 20 (Finland)	<ul style="list-style-type: none"> - Discussion of the data collection experience - Presentation of the data on student engagement in classroom situations - Evaluation of the teaching units and the data collection period
2015	Two-day workshop, December 8–9 (Finland)	<ul style="list-style-type: none"> - Three-dimensional learning - Asking questions, use of evidence, and modeling - Teaching unit planning
2016	Two-day workshop, January 18–19 (Finland)	<ul style="list-style-type: none"> - Project-based learning - Scientific practices and engagement - Teaching unit planning
2016	Three-day workshop, February 6–9 (US)	<ul style="list-style-type: none"> - Three-dimensional learning - Joint teaching unit planning by Finnish and US teachers
2016	February (in participating Finnish schools) <i>Implementation and data collection in Finnish schools</i>	<ul style="list-style-type: none"> - Teaching unit planning by a group of teachers on the school site - Researcher visit to the school site
2016	One-day workshop, May 21 (Finland)	<ul style="list-style-type: none"> - Discussion of the data collection experience - Presentation of the data on student engagement in classroom situations - Evaluation of the teaching units and the data collection period
2017	Afternoon meetings (August—September) two-day seminar, November 13–14 (Tallin)	<ul style="list-style-type: none"> - Co-planning of teaching units - Co-designing of teaching units
	December 14	<ul style="list-style-type: none"> - Co-planning of student evaluation instrument
2018	January 23	<ul style="list-style-type: none"> - Meeting with US teachers in Helsinki